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Title of Research: **"Galactic Globular Cluster Infrared Fluxes"**

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ABSTRACT

The goal of this research program was to measure the near infrared fluxes of selected bright galactic globular clusters, using the IRAS database. Graduate student Tyson has used IPAC facilities to process Additional Observations of eleven clusters, and 2D survey coadditions for a further eight clusters. All nineteen clusters were detected at 12 microns, while 13 were detected at 25 microns, and only one (47 Tuc) was detected at longer wavelengths. One and two dimensional King profile filters have been developed to optimize the signal to noise ratio of the cluster flux measurements. Detailed comparison with the infrared fluxes of early type galaxies will be undertaken once unpublished K band magnitudes have been obtained from a colleague.

1. INTRODUCTION

We are interested in whether the globular cluster 12μm fluxes exceed what is expected from photospheric emission alone. It would then be reasonable to associate the excess flux with intracluster, possibly circumstellar dust.

Evolutionary calculations (e.g. Rood 1973, Renzini 1981) indicate that globular cluster stars (mass < $1M_{\odot}$) at the turnoff) should lose about $0.2M_{\odot}$ during the red giant phase and a further $0.1M_{\odot}$ during second ascent. This mass loss seems to be required to fit the observed horizontal branch morphologies (Dupree 1986, Iben and Renzini 1983, Sweigart and Gross 1978).

Prior to IRAS the only observational evidence for mass loss in lower metallicity stars was the emission seen in the wings of Hα (e.g. Cacciari and Freeman 1983,.Cohen 1976). However, Dupree, Hartman, and Averett (1984) use stellar atmosphere models to show that asymmetric Hα lines can arise in the static chromospheres of population II giants, and thus mass loss rates could be $<< 2 \times 10^{-9}\ M_{\odot}$/yr, a factor of 20 – 50 less than for population I stars. We must therefore rely on the 12μm excess as solid evidence of mass actually lost, rather than the Hα assymetry observed in the chromosphere of cluster giants. Frogel and Elias (1988), however, link significant near IR excess in clusters to the presence of luminous long period variables (LPVs). They also note that stellar pulsation will considerably increase, and possibly dominate the mass-loss rate over that predicted from the effects of radiation pressure alone.

Given the scarcity of information on mass-loss from population II giants and the importance of mass-loss both for the calculation of the late stages of stellar evolution, and the chemical enrichment of the Galaxy, the detection of excess IRAS flux is exciting. If mass-loss is radiation-pressure dominated then the appropriate rate can be estimated from following the momentum conservation method where $(dM_{gas}/dt)\,V_{\infty} = L_{IR}/c$ (e.g. Zuckerman 1986). If mass loss is pulsation-dominated then the process may be stochastic for any individual star. The very high mass-loss rates for LPVs inferred in Frogel and Elias (1988) suggest it may be better to characterize mass loss by averaging over an ensemble of globular clusters at a given metallicity thus allowing a statistical study of mass-loss in a well-defined sample of $> 10^4$ giants.

A second level of inquiry is to determine the mass-loss as a function of age and metallicity. For example, one expects mass-loss episodes in intermediate-age clusters. We now have a key opportunity to characterize the dependence. Rood (1973) found that such an effect could help explain cluster horizontal branch morphologies, while the results of Dupree, Hartmann, and Avrett (1984) indicate lower mass-loss rates in lower metallicity stars. The 34 target clusters of this study differ in metal abundance by nearly two orders of magnitude which should be sufficient to test the mass-loss dependence on metallicity.

The amount of stellar mass loss might also be found to depend on the horizontal branch type of the clusters. We have compiled for each cluster the parameter B/(B+R). Here B and R are the estimates of the number of blue and red horizontal branch stars seen in the cluster. Values range from zero to one, although this parameter might be best characterized through IUE observations. The connection between this parameter and mass loss arises from the fact that red horizontal branch stars have substantial convective envelopes whereas the blue stars are almost bare stellar cores. For stars of the same age, more mass must be shed during the red gant phase to make the blue horizontal branch stars. All other parameters being identical, one would assume that the giants in a cluster with a blue horizontal branch would be losing more mass at the first giant branch tip. Thus, there is strong suspicion that a correlation should exist between horizontal branch morphology and 12μm excess.

2. RESULTS

Tyson visited IPAC to use the IRAS data base in an attempt to detect 12μm and 25μm emission from 34 target globular clusters. This involved extensive interaction with M. Bicay of IPAC before, during, and subsequent to the visit.

IRAS additional observations (AOs) were available for eleven out of 34 clusters. Eight had full resolution 2D survey coadds available that were produced on IPACs older IBM main-frame. Two dimensional maps of the remaining fifteen were only available through the provisional "BIGMAP" IPAC software which processes the four IRAS bands only to the resolution of the 100μm detector. Tyson was told by IPAC support staff that full resolution two dimensional image reduction software should be available by March on their recently-acquired CDC Cyber computer.

Nineteen globular clusters were detected at 12μm, of which five have definite 25μm emission (S/N > 5) and seven have possible 25μm emission (S/N < 2). Despite this success at 12μm and 25μm only 47Tuc has 60μm and 100μm emission. (See Gillett, *et al.* 1988). These detections represent every cluster for which either AOs or full resolution 2D coadds existed. The signal-to-noise for all of the low resolution BIGMAP coadds was ~1.We conclude that if full resulution 2D coadds were available for the balance of the clusters then positive detections would be likely.

Aside from the five globular clusters detected by Helfand and Applegate (private communiation, unpublished) this represents the *largest* reported sample of globular clusters detected by IRAS. While these nineteen detections are important, the intent of this study is to determine IR excess over what is to be expected from photospheric emission from cluster giants.

For the twelve clusters with 12μm and 25μm detections we can compare the 12-to-25μm flux ratio with that expected from the Rayleigh-Jeans relation $S_\nu \propto n^2$. Such a comparision reduces the sensitivity to the background noise subtraction. For pure stellar photospheres, the ratio is 4.3. A ratio less than 4.3 suggests the existence of warm intracluster dust; possibly circumstellar shells from RG mass loss. Notice from Table 2 that the flux ratio for four clusters is significantly *less* than 4.3. (The other clusters fall between 4.0 and 8.0.) These preliminary results provide confidence in the posibility of other clusters showing excess when we conduct the detailed analysis.

We are now ready to compare the 12μm and 25μm fluxes with existing near infrared and optical fluxes to determine a template spectrum for old population II stars. This is not a trivial task since similar IR fluxes are observed for a variety of V_{tot}. The 2.2-to-12μm flux ratio will be compared to those already determined for stars in the bulge of our Galaxy (Frogel and Whitford 1987), the bulge of M31 (Soifer, *et al.* 1986), and early type galaxies. These estimates can be supplemented by the existing information on the luminosities and temperatures of individual giant stars which can be used to obtain alternative 12μm flux estimates.

Further refinement requires an application of the King function template. Once the cluster photospheric light is modelled, the flux profile is subtracted to reveal possible residuals which we may associate with IR emission from circumstellar dust. Due to limited time at IPAC Tyson could not apply the King function template to the clusters on location.

Now that Tyson has the data he will conduct this analysis over the next six months here at Columbia.

The cluster fluxes in Table 1 are provisional until a more detailed analysis of the stability of the background noise can be conducted; many estimates of the background were contaminated by bad pixels. Consequently, the reported fluxes are accurate to 20 percent but we ultimately expect to reduce the uncertainty to less that 10 percent based on what was achieved in Gillett, *et al.* (1988).

The manner in which Tyson obtained the integrated fluxes permits a 1D comparison with the King profile. Each cluster flux was measured through several (typically five or six) concentric apertures that ranged from slightly larger than the core radii up to ten core radii. This provides a radially dependent integrated cluster profile that can be compared with an appropriate King profile that has been convolved with the detector response function. For the brighter clusters, a 2D version of this profile comparision is available from Michael Bicay at IPAC. He has written software that computes the spatial correlation of emission between any two photometric bands (cf. Bicay, *et al.* 1989). Bicay has already run his 2D spatial correlation algorithm with the optical King profile on 47Tuc and he is currently running it on ω Cen. We have arranged that this analysis be conducted on the seven clusters with the largest angular extent.

In March, full resolution survey coadds for all four IRAS bands will be available through the modified and improved BIGMAP software. The15 clusters for which AOs and full resolution 2D coadds were not available during Tyson's latest trip to IPAC will be run at that time.

At IPAC, M. Melnyck is developing specialized code based on the Richardson-Lucy 2D mapping algorithm that reconstructs the individual IRAS scans to obtain resolution that is three times better than what is quoted for the band-averaged detector profiles. Tyson has been encouraged by the support staff to return to IPAC in October 1990 when this software is expected to come on line. Two dimensional coadds at three times the current resolution will permit us to characterize the cluster structure as well as the total cluster emission. In particular, the correspondence of any intracluster dust with the stellar component will help to determine whether indeed intracluster dust represents circumstellar shells from RG mass loss or dust accretion from successive passes through the Galactic disk. It will also help to isolate individual sources within the cluster which may not be centrally distributed (e.g. Gillett, *et al.* 1986).

The successful 12μm detections reported herein suggest exciting future paths:

1) Extend the current work to include IRAS photometry of *all* globular clusters in the Galaxy.

2) Conduct high resolution IRAS photometry on the Magellanic cloud globular clusters.

3) To simultaneously address the same questions from a different wavelength we note that for stars with extreme mass loss we expect blue stellar cores. In particular, high mass loss at the AGB tip would produce blue stars without an obscuring envelope. If the process is rapid, the cluster's horizontal branch morphology can be altered significantly by a change in the relative frequency of red to blue giants.

Table 1: GLOBULAR CLUSTER DETECTIONS

NGC	Name Band 1: Band 2: Band 3: Band 4:	Aperture 1	Aperture 2	Aperture 3	Aperture 4	Aperture 5	Aperture 6	Rc	Vtot	[Fe/H]	B/(B+R)
		(Aperture Flux Measurements in Janskys)									
104	47 Tuc	2.400	4.200	6.000	7.800	12.000		0.39	3.83	-0.71	0
	12um	3.105	7.230	9.291	10.465	12.077					
	25um	0.831	2.035	2.755	3.106	3.696					
	60um	0.146	0.224	0.252	0.332	0.325					
	100um	0.213	0.419	0.661	1.176	2.041					
362		0.600	1.800	3.000	4.800	7.800		0.21	6.46	-1.27	0.05
	12um	0.019	0.292	0.567	0.749	0.881					
	25um	0.005	0.081	0.211	0.389	0.860					
3201		2.400	3.000	4.800	5.400	7.200		1.09	6.68	-1.61	0.54
	12um	0.297	0.445	0.846	0.988	1.413					
	25um	0.063	0.092	0.194	0.237	0.355					
5139	wCen	1.800	4.200	5.400	7.200	10.200		2.62	3.52	-1.59	0.95
	12um	0.610	3.462	5.079	7.556	10.103					
	25um	0.179	0.987	1.422	2.184	3.054					
5272	M3	1.200	1.800	4.200	6.000	10.200		0.42	5.92	-1.66	0.55
	12um	0.074	0.152	0.492	0.550	0.550					
5904	M5	1.200	1.800	3.000	6.000	10.200	12.000	0.44	5.69	-1.4	0.76
	12um	0.088	0.206	0.487	0.955	1.196	1.217				
6121	M4	2.000	3.750	6.000	10.000	15.000	20.000	1.23	5.76	-1.33	0.44
	12um	1.146	2.883	4.964	8.005	12.492	16.223				
6205	M13	1.000	2.400	4.800	7.800	13.200		0.83	5.68	-1.65	1
	12um	0.096	0.364	0.929	1.299	1.798					
	25um	0.021	0.085	0.227	0.335	0.335					
6218	M12	1.000	2.500	4.000	6.000	9.000	15.000	1.18	6.77	-1.61	0.95
	12um	0.071	0.362	0.606	0.867	1.035	1.167				
	25um	0.032	0.061								
6254	M10	1.000	2.000	3.000	5.000			0.70	6.55	-1.6	0.94
	12um	0.138	0.448	0.755	1.118						
	25um	0.026	0.112	0.203	0.251						
6266	M62	0.750	1.500	2.250	3.000	5.000	7.000	0.24	6.68	-1.28	...
	12um	0.368	1.222	2.111	2.950	5.068	7.018				
	25um	0.079	0.228	0.306	0.366						
6341	M92	0.500						0.31	6.39	-2.24	0.97
	12um	0.167									
6388		0.500	1.000	2.000	3.000	4.000	6.000	0.15	6.73	-0.74	...
	12um	0.171	0.577	1.513	2.389	3.059	3.923				
	25um	0.043	0.141	0.367	0.556	0.693	1.062				
6397		1.000	2.000	2.750	4.000	5.000	6.000	0.78	5.75	-1.91	0.91
	12um	0.150	0.522	0.847	1.380	1.793	2.194				
6541		0.600	1.800	3.000	4.200	6.000	10.200	0.28	6.08	-1.83	0.94
	12um	0.008	0.146	0.360	0.538	0.694	0.709				
6752		1.000	2.000	3.000	5.000	7.000	10.000	0.49	5.48	-1.54	1
	12um	0.177	0.615	0.987	1.426	1.632	1.635				
	25um	0.039	0.112								
7078	M15	0.600	1.800	4.200	6.000			0.09	6.02	-2.15	0.81
	12um	0.011	0.192	0.560	0.617						
	25um	0.005	0.072	0.086							
1851		0.600	1.200	1.800	4.200						
	25um	0.011	0.084	0.169	0.341						
6441		0.600	1.800	3.000	4.800	7.200	9.000	0.14	7.19	-0.59	...
	12um	0.049	1.474	6.304	17.276	36.716	44.672				
	25um	0.008	0.164	0.680	3.745	19.530	28.031				

Table 2: Flux Ratios

NGC	Name	12um/25um
104	47 Tuc	3.3
362		1.0
3201		4.0
5139	Omega Cen.	3.3
6205	M13	5.4
6218	M12	5.9
6254	M10	4.4
6266	M62	8.0
6388		3.7
6752		5.5
7078	M15	6.5

Notes to Table 1

— Apertures (in bold) are radii in arc minutes
— Rc is the core radius in arc minutes from Madore (1980).
— Vtot are total visual magnitudes from Webbink (1985).
— Metal abundances [Fe/H] are from Zinn and West (1984).
— Horizontal Branch types B/(B+R) are from Zinn (1980).
— There was possible contamination from a nearby source in the flux levels for NGC 6441

Notes to Table 2

The flux ratios are taken from the largest aperture where the 25um emission can be distinguished from background noise (S/N > 2).

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